Jet Propulsion Laboratory
California Institute of Technology

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Development of an Evaporator Using Porous Wick Structure for a Two-Phase Mechanically Pumped Fluid Loop

Takuro Daimaru, Ben Furst, Stefano Cappucci, Eric Sunada
Terry Hendricks, Pradeep Bhandari, Gaj Birur
NASA/JPL

Two-Phase Mechanical Pump Fluid Loop (2MPFL)

Working Principle

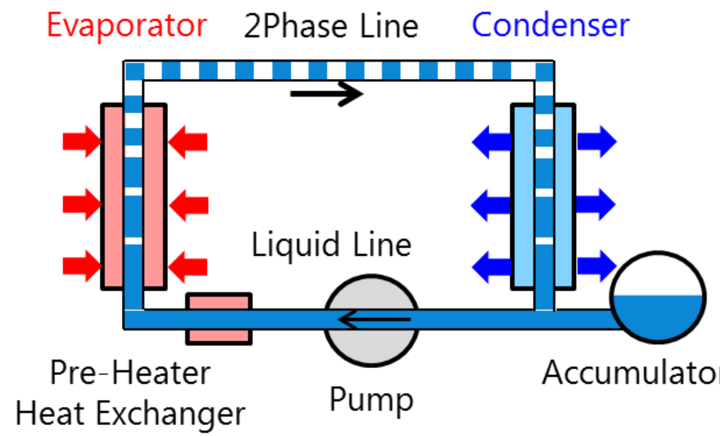
- Fluid Driven by Pump
- Evaporator: Liquid → Two-Phase
- Condenser: Two-Phase → Liquid
- Temperature Control by Accumulator

Merits

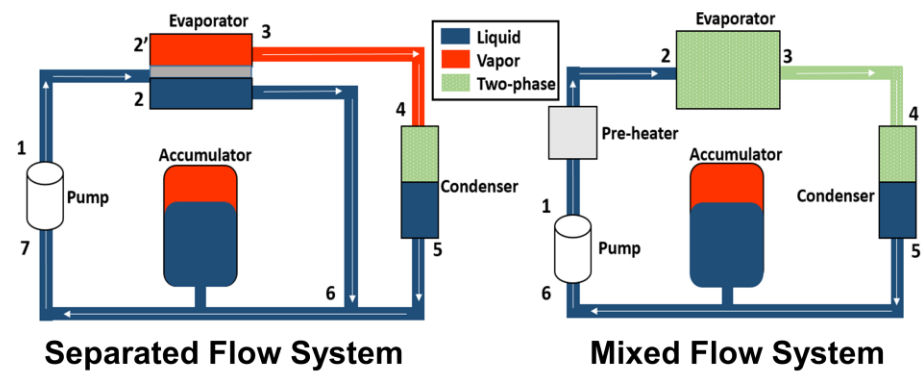
- Pump Driving
  - Long Distance / Robust Start-up
- Phase Change
  - Isothermality / Lighter System

System Architecture

- Mixed Flow System
  - Preheating / Two-Phase flow
- **Separated Flow System**
  - No Preheating / Vapor Flow



2MPFL



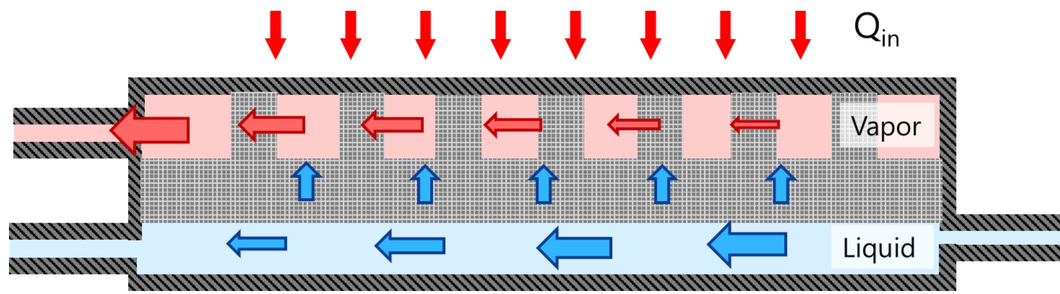
System Architecture

(Furst 2017)

Evaporator Design Concept

Requirement from System

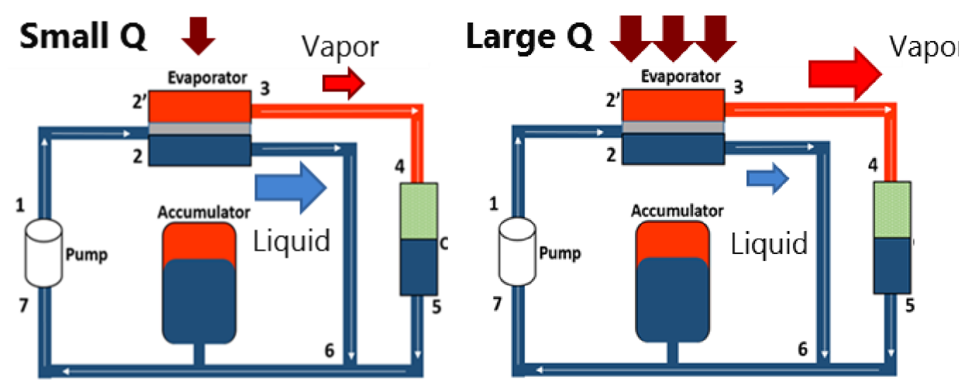
- Heat Dissipation: up to 500 W
- Heat Flux: up to 5 W/cm^2
- Temperature Gradient: < 2^{o}C



Wick-Type Evaporator

Wick-Type Evaporator

- Working in Separated Flow System
- Phase Separation
- Ability to Adjust Mass Flow Rate to Q
    - ➢ Wick pulls liquid up as needed



Mass Flow Adjustment to Q

Heat Transfer in Wick-Type Evaporator Odagiri (2017)

Low Heat Flux Mode

- Liquid Bridge Forms
  - ➢ Curvature Changes with Required Pressure Increase in Evaporator
- Ultra-Thin Liquid Film Evaporation
- **Good Heat Transfer**

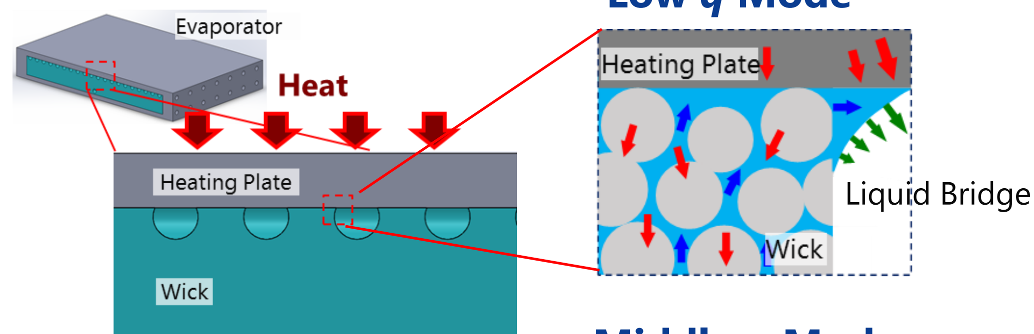
Middle Heat Flux Mode

- Combination of Liquid Bridge Evaporation and Nucleate Boiling
- **Good Heat Transfer**

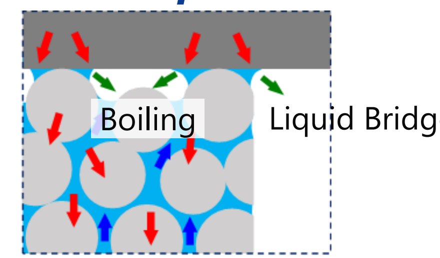
High Heat Flux Mode

- Vapor Pocket Forms
- **Bad Heat Transfer**

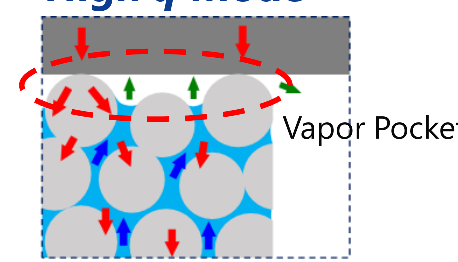
Low *q* Mode

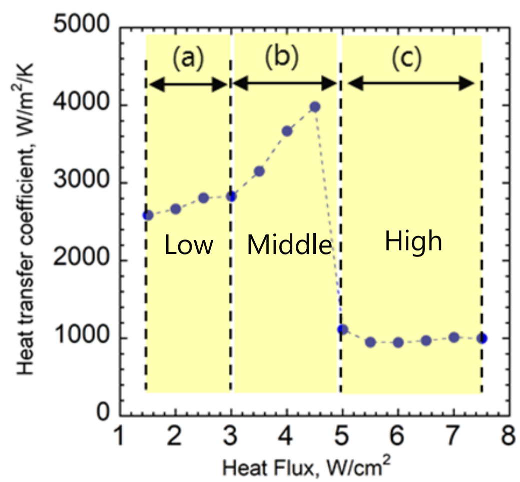


Middle *q* Mode



High *q* Mode





Change of Heat Transfer Coefficient (Odagiri 2017)

Objective

To design an evaporator which meets requirement from system and to archive high thermal performance by utilizing heat transfer phenomena in wick

Design Approach

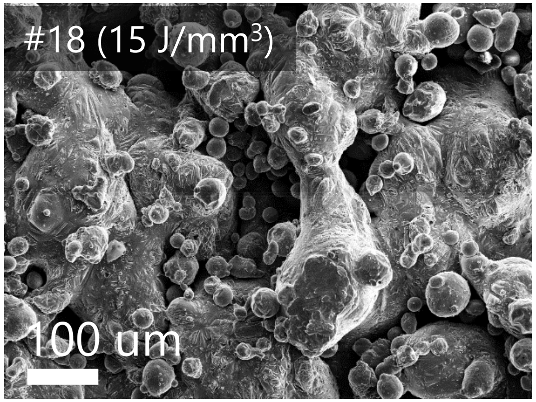
1. Wick Material Selection
   - Database of 3D printed wick properties
2. System Level Calculation
   - Estimation Required Pressure Increase in Evaporator
3. Operational Limit Estimation
   - Transition from middle to high q mode
4. Wick Geometry Design
5. Thermal Performance Calculation
   - Based on Heat Transfer Coefficient Model by Odagiri (2017)

1. Wick Material Selection

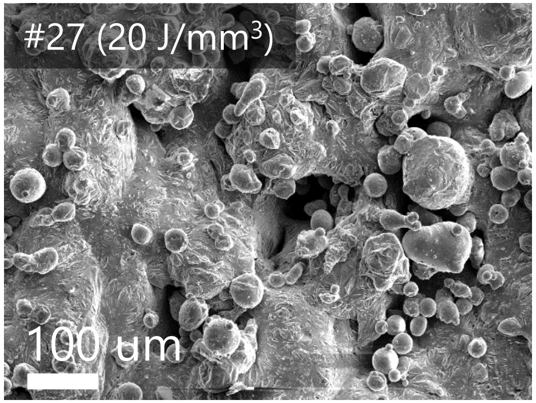
Database of 3D printed wick properties

Wick Pore Radius and Permeability

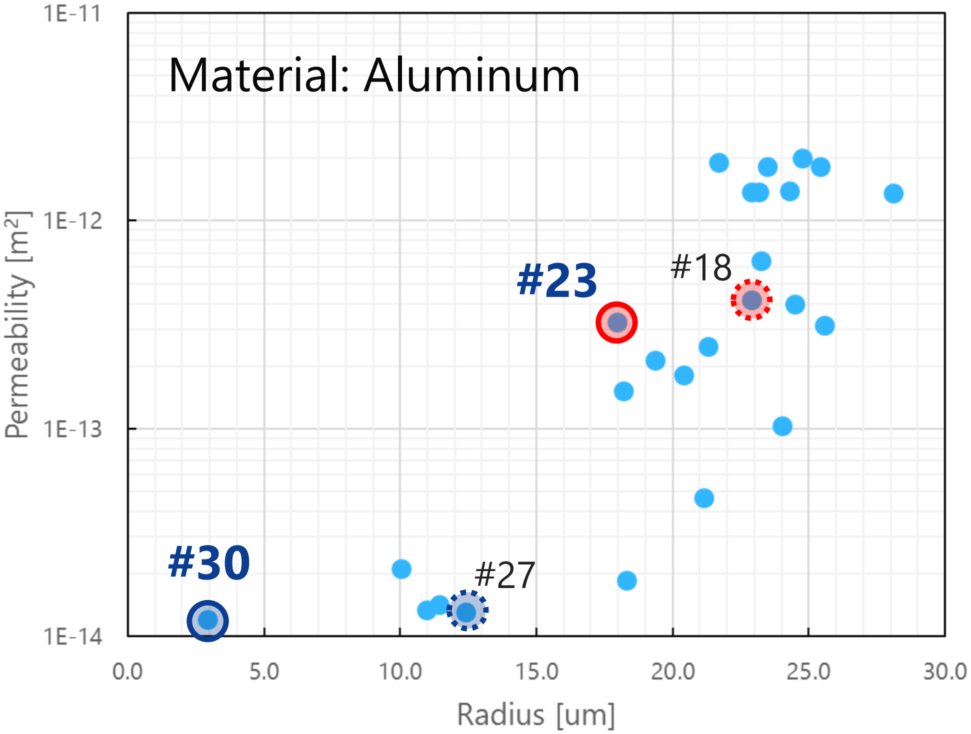
- **Small Pore Radius**: Operation in Wide Heat Input Range
- **High Permeability**: Low Pressure Loss in Wick



Baseline
#23 (15J/mm³)
Pore Radius: 18.0 um
Permeability: $3.2*10^{-13}$
Porosity: 22.3 %



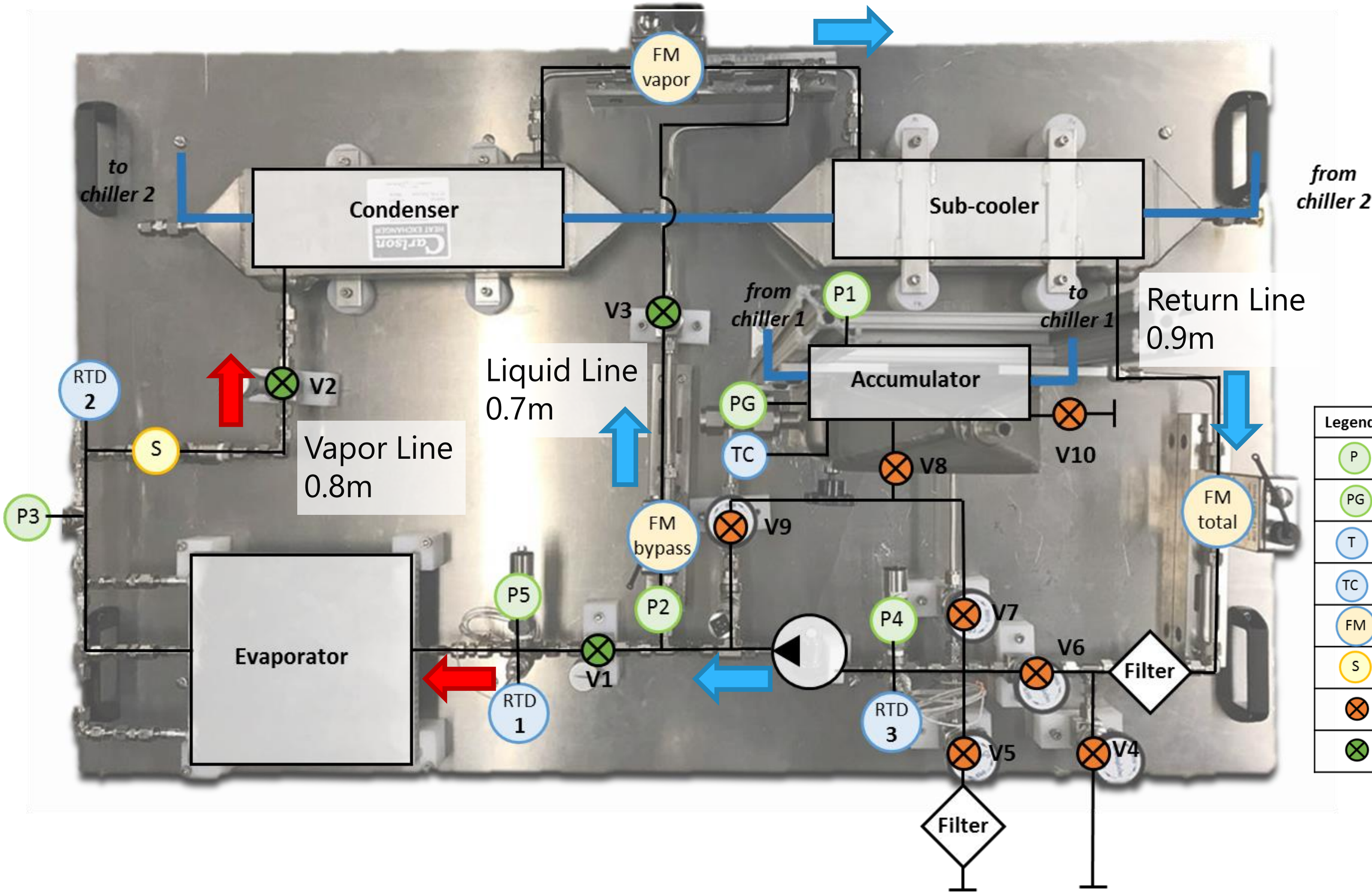
Challenge
#30 (20J/mm³)
Pore Radius: 2.9 um
Permeability: $1,2*10^{-14}$
Porosity: 12.2 %



2. System Level Calculation

Estimation Required Pressure Increase in Evaporator

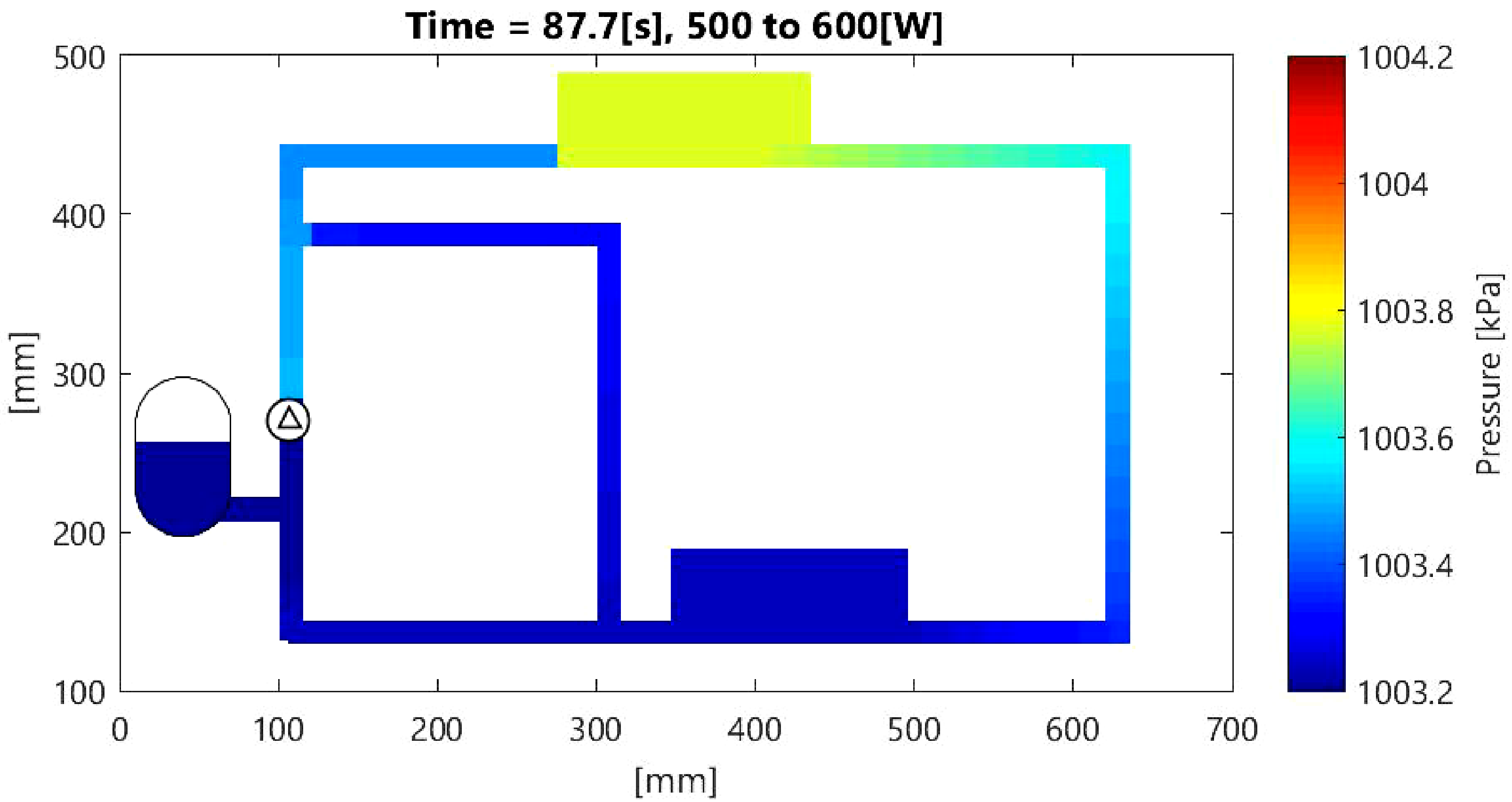
Test Bed Loop Configuration (Fluid: Ammonia)



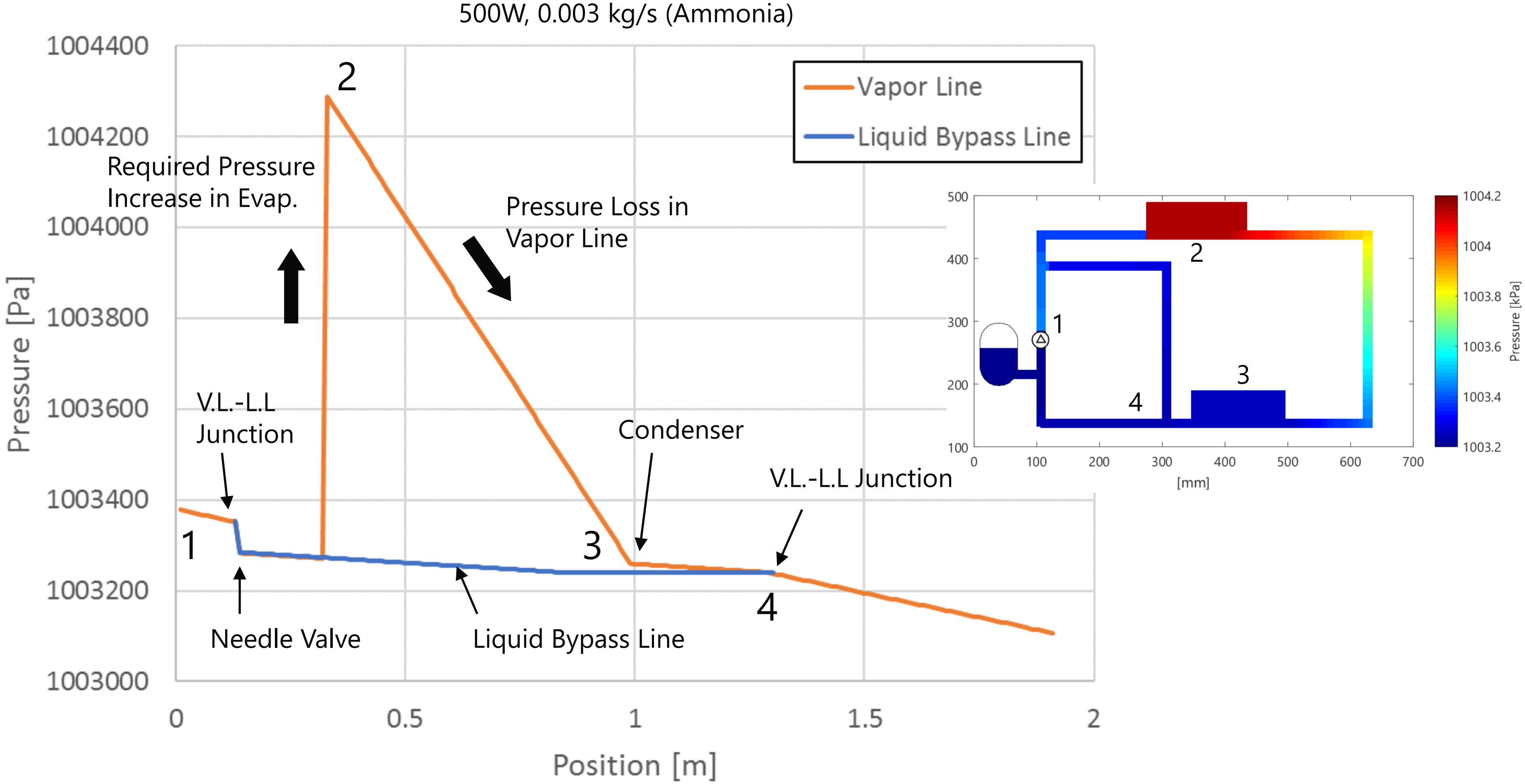
Legend

P	Press. transducer (abs.)
PG	Pressure gauge (analog)
T	Temperature gauge
TC	Thermocouple
FM	Flow meter
S	Sight glass
(orange ⊗)	Ball valve
(green ⊗)	Needle valve

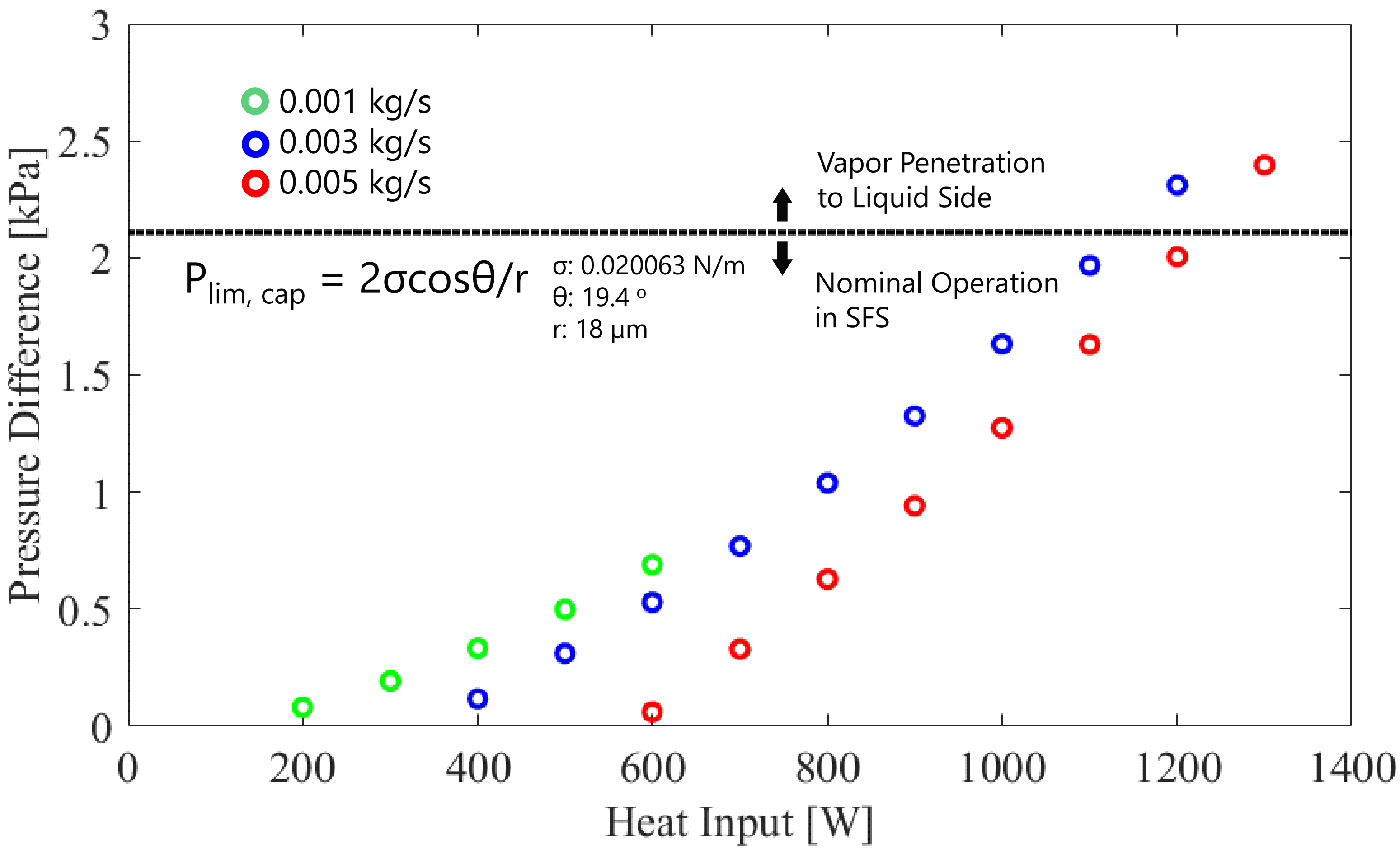
Example of Transient Calculation (Pressure)



Pressure Profile in Loop



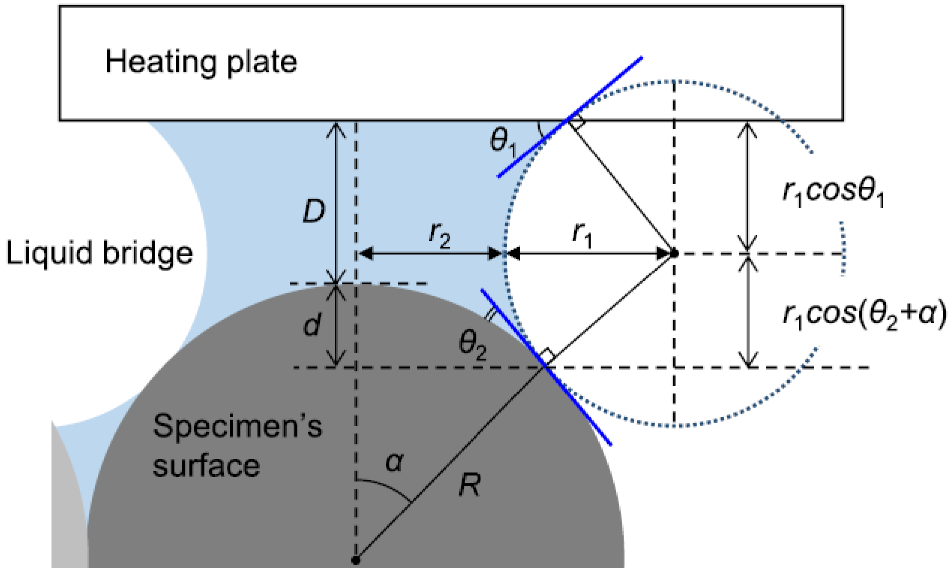
Required Pressure Increase in Wick



3. Operational Limit Estimation

Transition from Middle q to High q Modes

Transition from Middle to High q Modes

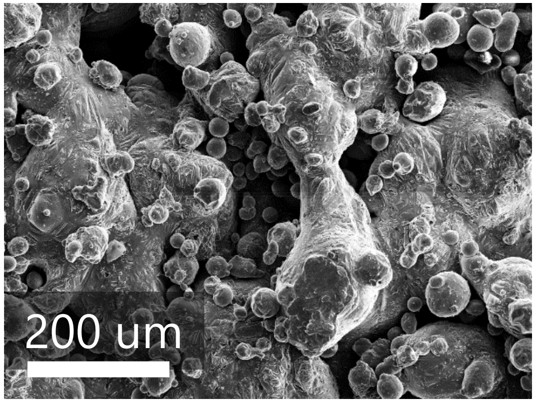


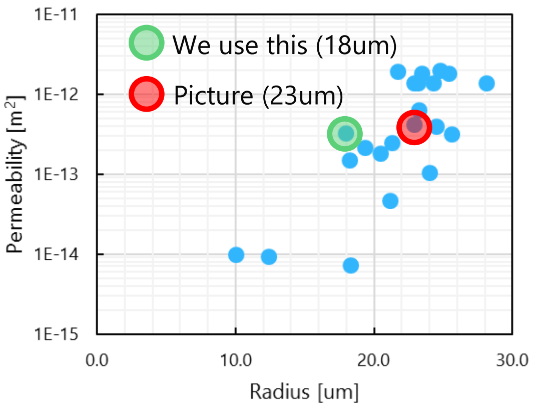
$$P_{cap} = \sigma \left(\frac{1}{r_1} + \frac{1}{r_2} \right) \quad (2)$$

$$r_1 = \frac{D + d}{\cos\theta_1 + \cos(\theta_2 + \alpha)} \quad (3)$$

$$r_2 = R\sin\alpha + r_1 \{\sin(\theta_2 + \alpha) - 1\} \quad (4)$$

Build #: 18, E.Density: 15
r_{pore}: 22.9um, K: 4.1×10^{-13}

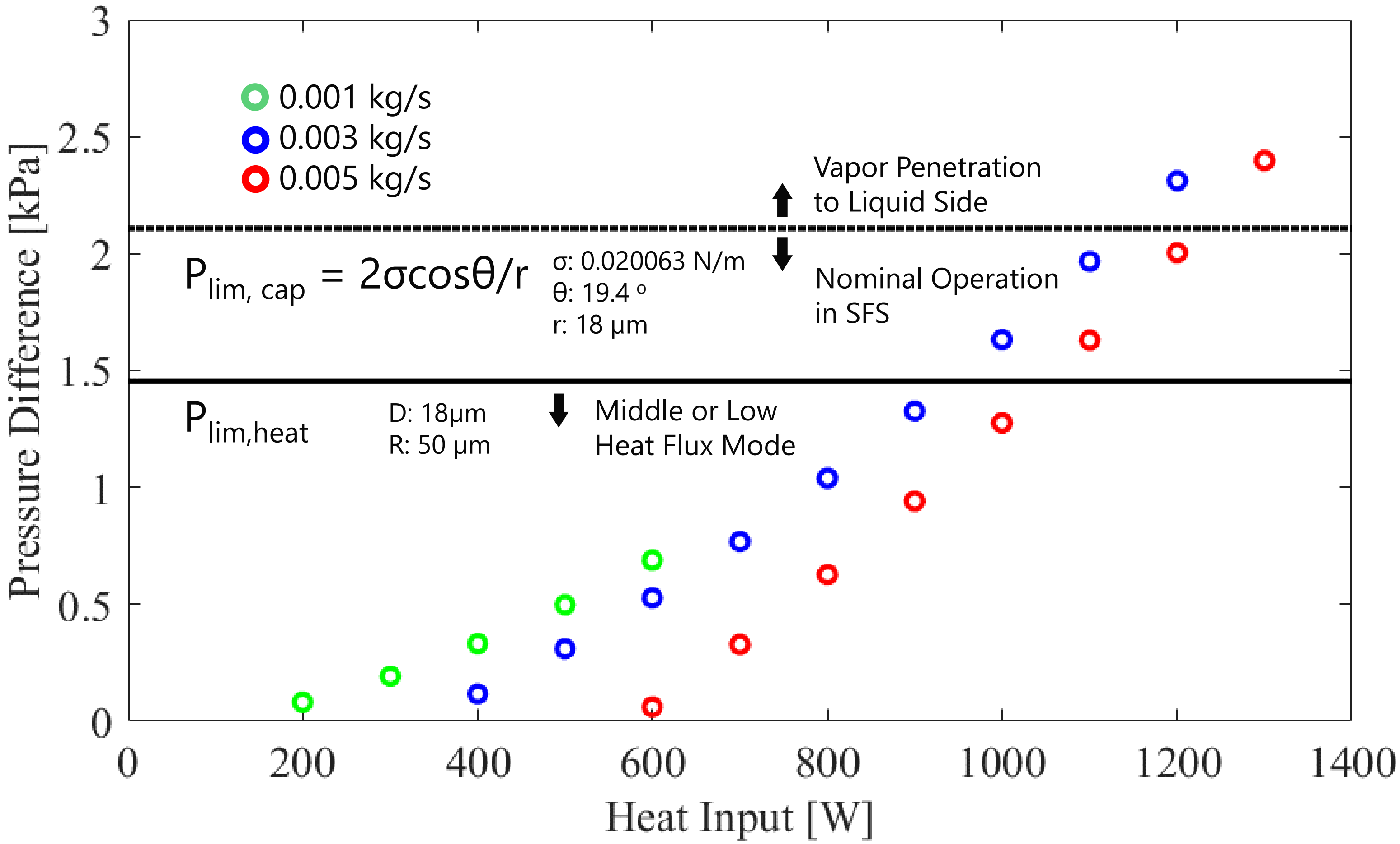




Selected Value… D = 18 μm, R = 50 μm

C Oka *et al* 2017 *Surf. Topogr.: Metrol. Prop.* **5** 044006

Transition from Middle to High q Modes



4. Wick Geometry Design

Wick Geometry Design

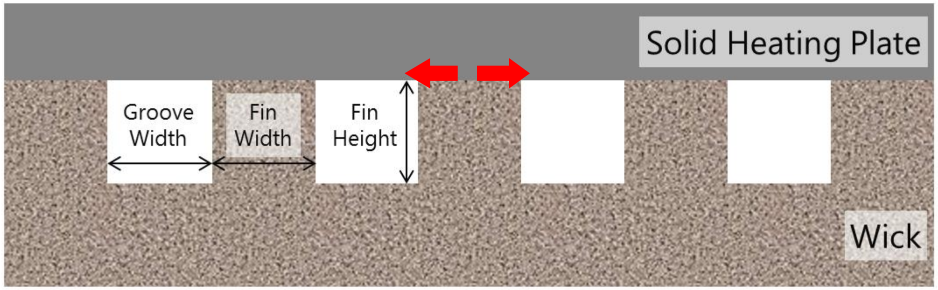
Parameters

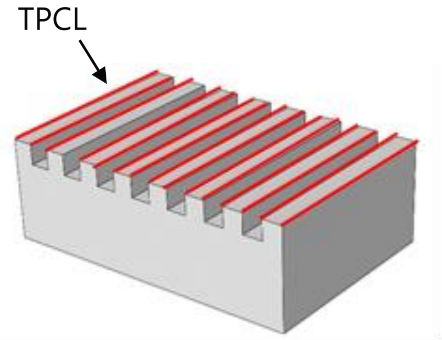
- Groove Width: Pressure Loss in Vapor Flow
- Fin Height: Pressure Loss in Wick
- Fin Width: Pressure Loss in Vapor Escape after Boiling

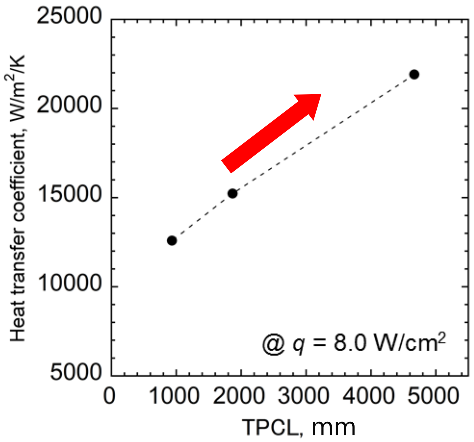
- **Triple Phase Contact Line (TPCL):** Higher Heat Transfer Coefficient

Constraint

- Minimum Resolution of A.M.
  - 1mm



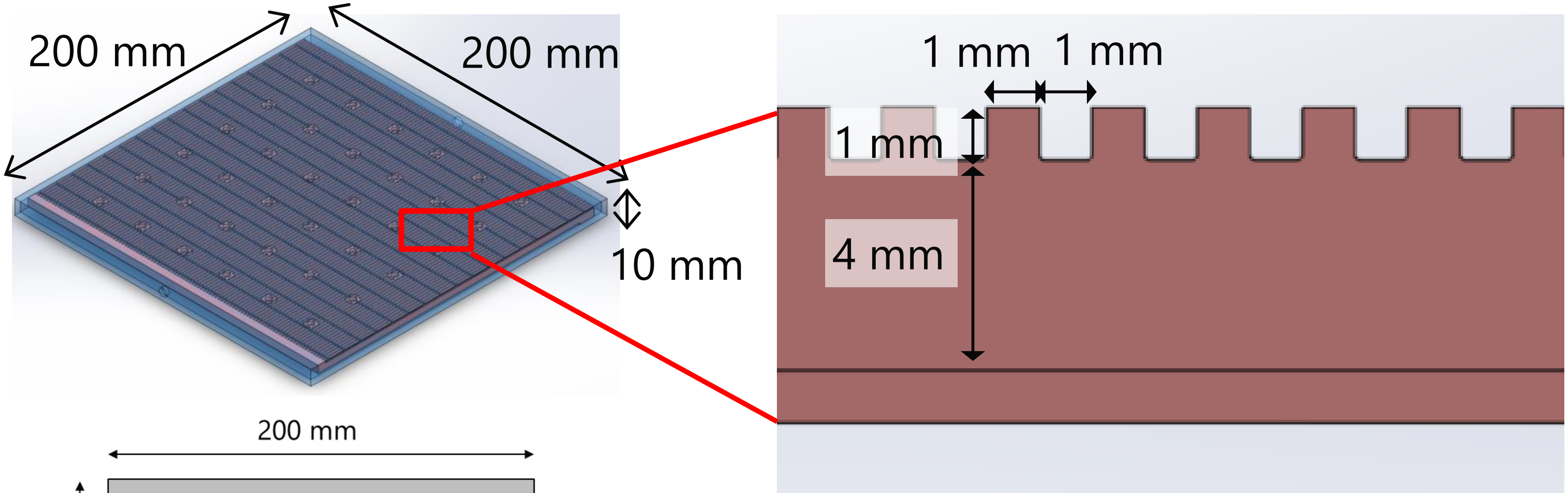


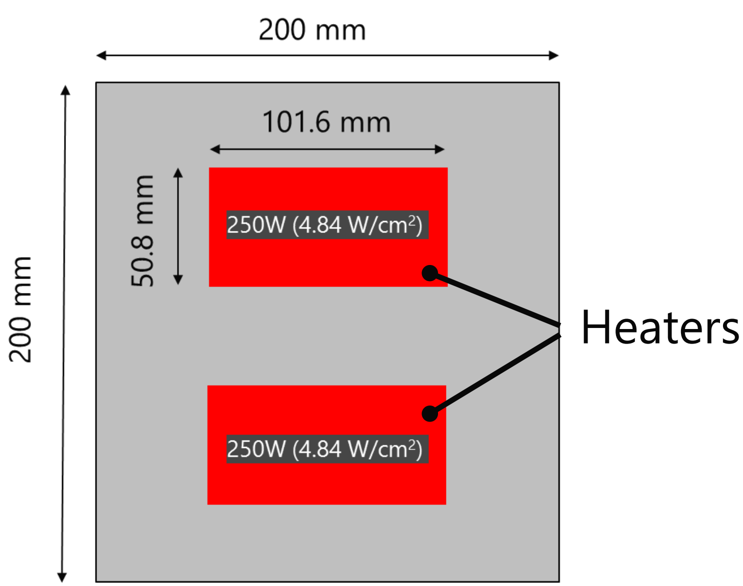


Increase of Thermal Performance with TPCL

Odagiri (2018)

Wick Geometry Design





Parameters

- Groove Width: 1mm
- Fin Height: 1mm
- Fin Width: 1mm
- Base Height: 4mm

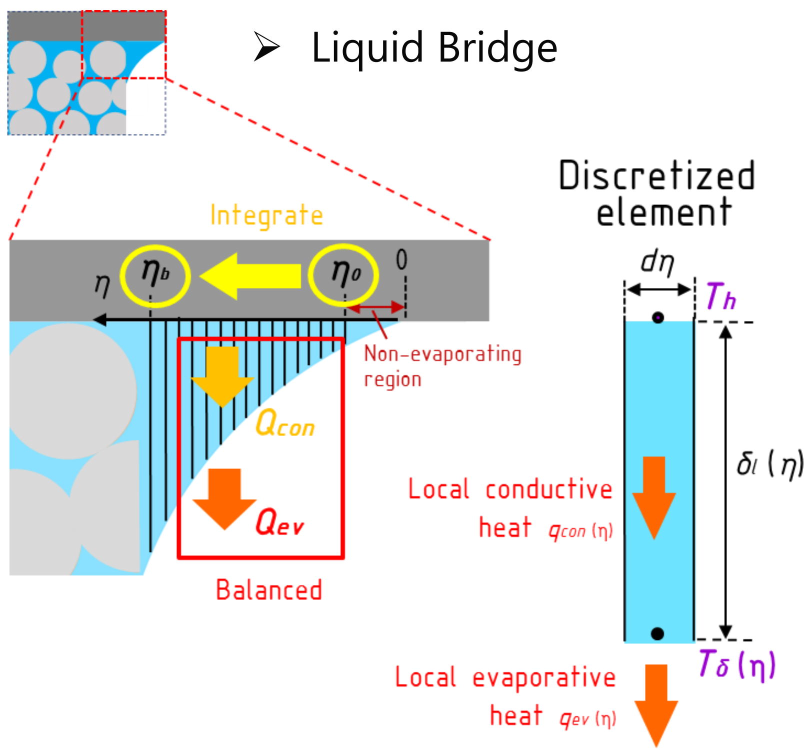
5. Heat Transfer Coefficient Calculation

Heat Transfer Coefficient Model

Odagiri (2017)

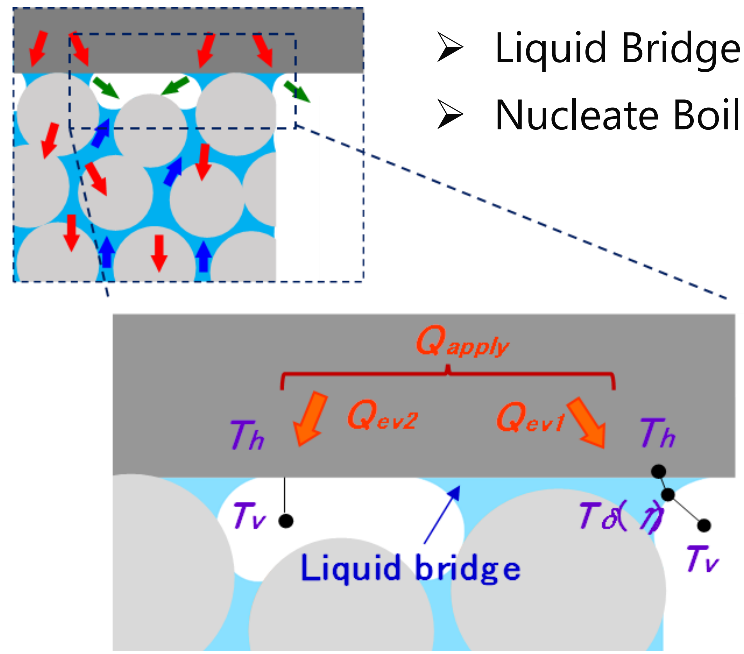
Low Heat Flux

- ➤ Liquid Bridge



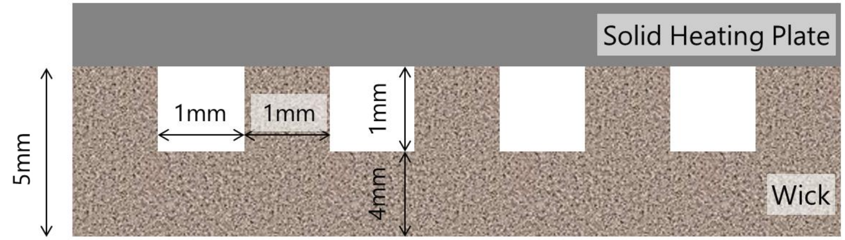
Middle Heat Flux

- ➤ Liquid Bridge
- ➤ Nucleate Boiling

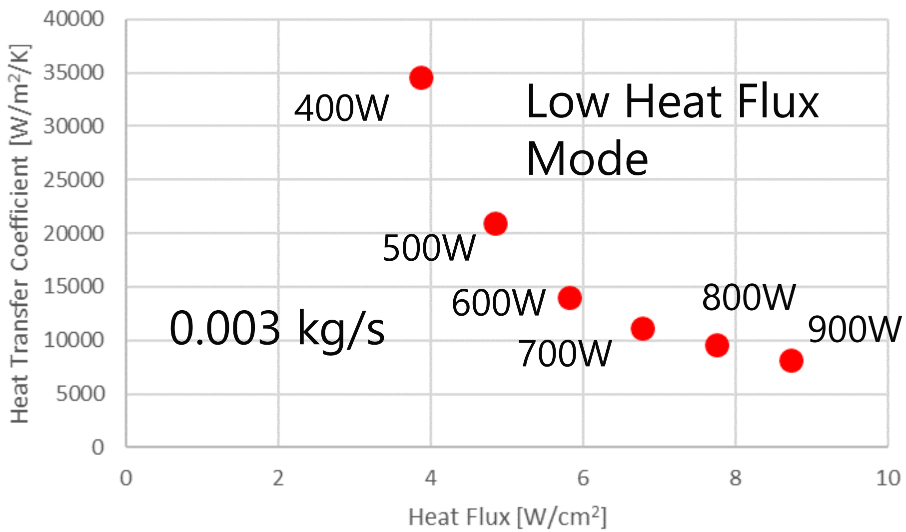


- Curvature of Liquid Bridge Changes by Required Pressure Increase Evaporator
  - ➤ Pressure Loss Value from System Level Calculation is Used

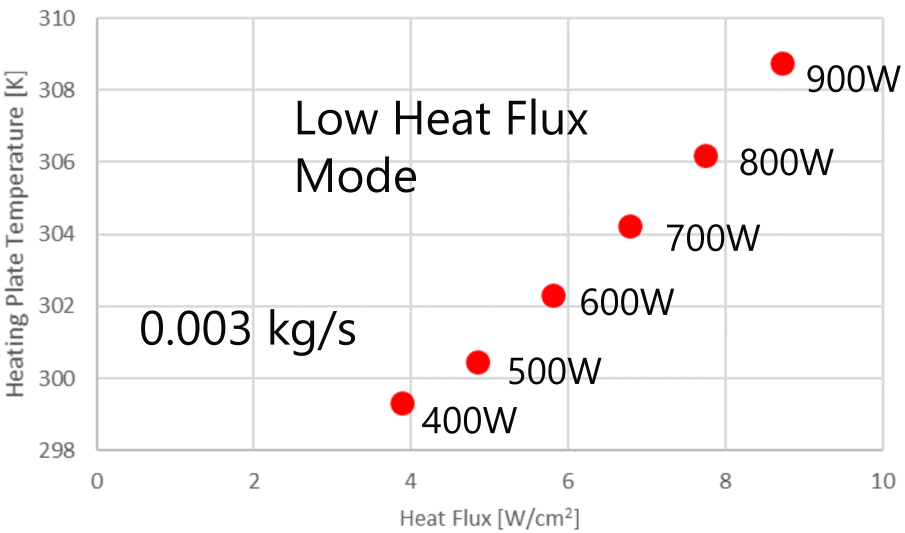
Thermal Performance of Designed Wick



Heat Transfer Coefficient

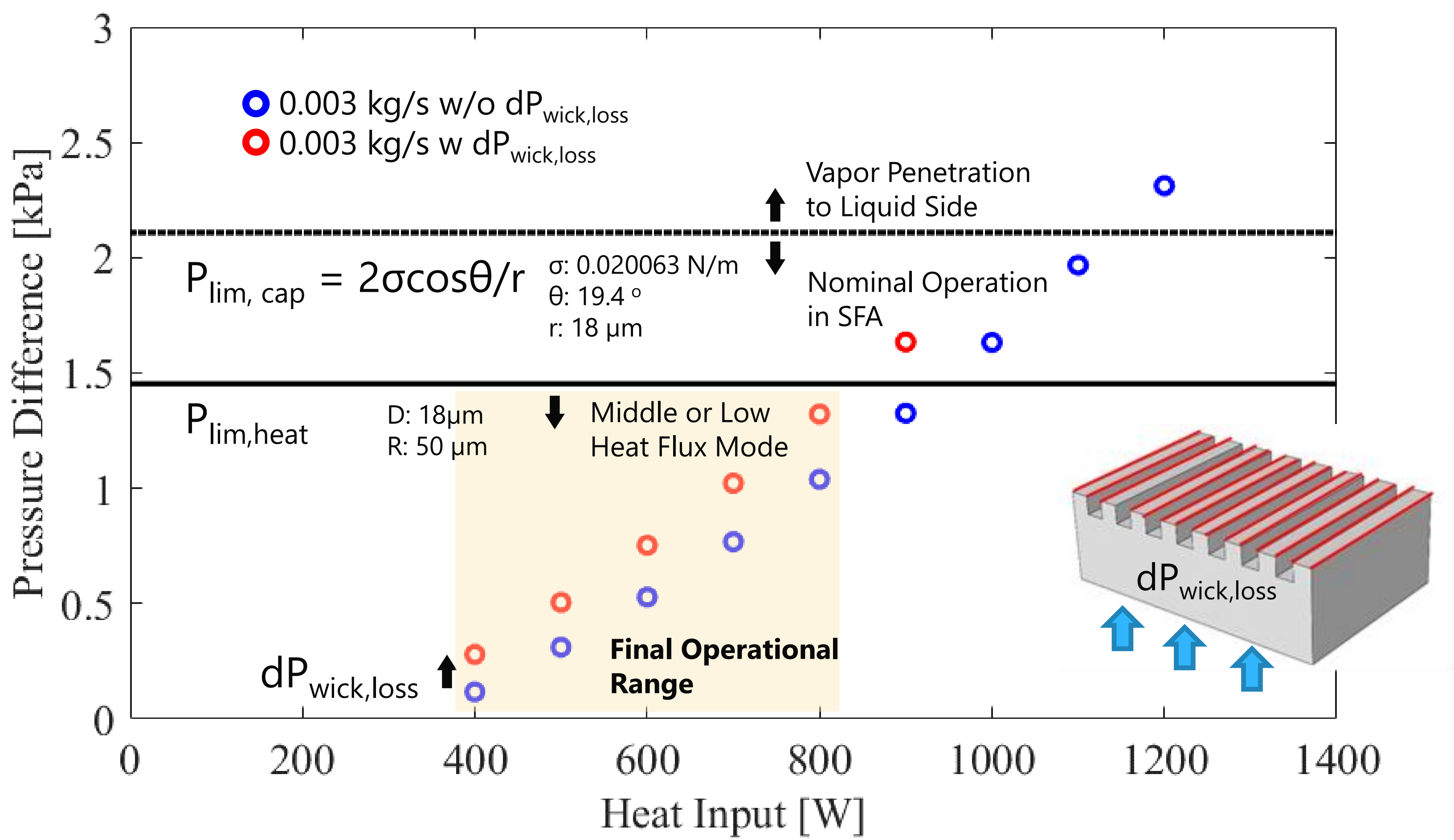


Heating Plate Temperature



(Vapor Temperature 298.15K)

Pressure Loss in Wick

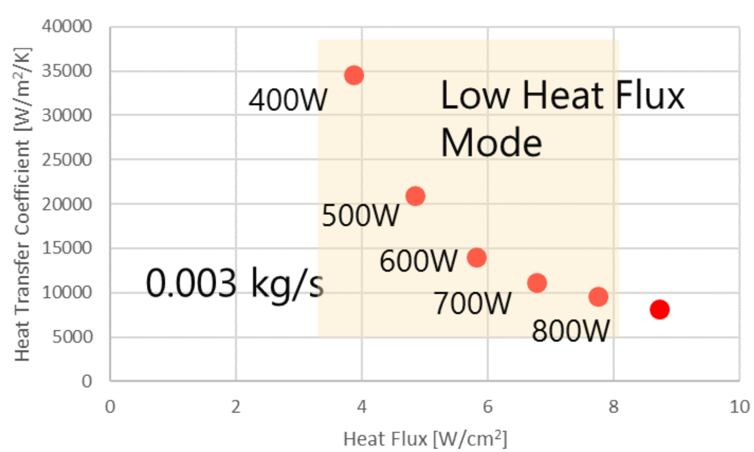


Summary

Designed an evaporator which meets system requirements. Thermal performance was optimized by basing on modeling of heat transfer phenomena in wick.

Thermal Performance of Evaporator

- Heat Transfer Coefficient: 10000 – 35000 $W/m^2/K$
- Heat Input: 400 – 800 W
- Heat Flux: 4 – 8 W/cm^2
- Temperature of Heating Plate: 299 – 306 K



Heat Transfer Coefficient

Future Works

- Experimental Validation of Evaporator Performance